CHECKLISTS OF THE FISH FAUNA OF THE LAURENTIAN GREAT LAKES AND THEIR CONNECTING CHANNELS

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ABSTRACT

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An accurate assessment, or inventory, of the species of an ecosystem is a necessary step towards the maintenance of that system's biodiversity. In order to gain the most benefit from an inventory, updates are needed to indicate changes over time. These changes can include establishment of species, both native and introduced, introductions that do not become established, and species that become extirpated or extinct. This is an attempt to inventory the biodiversity of the fishes of the Laurentian Great Lakes (Lakes Nipigon, Superior, Michigan, Huron, St. Clair, Erie and Ontario) by updating checklists of established, introduced and extirpated/extinct fishes. At the time these lists were completed (August 2000), there were 142 established fishes in the Great Lakes, 25 of which are introduced. Lake Michigan has the greatest number of total established fishes, while Lake Erie has the greatest number of introduced fishes, both established and reported. Twenty-six fishes have been extirpated from one or more of the lakes, four of which are now globally extinct. Lake Ontario has suffered the greatest loss of fish species at 14. It is difficult to compare our checklists with those published in the past due to several factors. However, this serves to strengthen our argument for the need for greater standardization of inventories. We anticipate the main cause of changes in biodiversity in the future to occur from continued introductions. In order to track potential changes in the biodiversity of any system and to determine the level of success of management programs, inventories need to be revised regularly.

RÉSUMÉ

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Une évaluation précise, ou un inventaire, des espèces peuplant un écosystème est une étape essentielle d'un programme de protection de la biodiversité de ce système. Afin de tirer le maximum d'avantages d'un tel inventaire, il faut le mettre à jour pour indiquer les changements qui se sont produits au fil du temps. Ceux-ci peuvent inclure l'établissement de nouvelles espèces, indigènes ou introduites, l'introduction d'espèces qui ne se sont pas établies et le déracinement ou la disparition d'espèces. Le présent document vise à établir un inventaire de la biodiversité des poissons des Grands Lacs laurentiens (lacs Nipigon, Supérieur, Michigan, Huron, Sainte-Clair, Érié et Ontario) en mettant à jour des listes de contrôle des poissons établis, introduits et déracinés ou disparus. Au moment où ces listes ont été parachevées (août 2000), les Grands Lacs abritaient 143 espèces de poisson établies, dont 24 étaient des espèces introduites. Le lac Michigan affichait le plus grand nombre d'espèces établies, tandis que le lac Érié montrait le plus grand nombre d'espèces introduites, tant établies que signalées. Vingt-six espèces avaient été déracinées d'un lac ou plus, dont quatre ont maintenant disparu de la planète. Le lac Ontario a subi les plus fortes pertes d'espèces, sa biodiversité s'étant appauvri de 14 poissons. Bien qu'il soit difficile de comparer nos listes de contrôle à celles publiées par le passé à cause de divers facteurs, elles servent à renfoncer notre argument à l'effet qu'il faut normaliser davantage les inventaires. Selon nous, les espèces introduites à l'avenir seront la principale cause des changements au plan de la biodiversité. Les inventaires doivent être révisés régulièrement afin de suivre de près les changements potentiels dans la biodiversité de tout système et de déterminer le niveau de succès des programmes de gestion.

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1.0 INTRODUCTION

Present concepts involving maintenance of biodiversity require; 1 – a precise statement of the area of interest, and 2 – an accurate assessment of the biodiversity at a specific time. That assessment should consist of a baseline, and regular revisions, or updates, indicating changes over time. A further benefit would be a history providing information on past changes. If possible, this history should include, in part, details of expansion or disappearance of both native and introduced species, dates of first introduction or discovery of introduced species, the reasons for the introductions, and details of demonstrable effects (positive and negative) on the native fauna, including effects on humans. Not all of those are included in this publication. Accurate knowledge of the existing fauna and the status of the various species are necessary components of effective management strategies operating at an ecosystem level. That requirement is more critical today as a result of the increased rate of change to which faunas are subjected. Developing inventories is not an easy task and they do have their shortcomings. One of the most serious is the fact that most become out of date by the time they are published. This is especially true for lists of introduced species. Electronic databases are considered to be the solution to this problem. However, to be effective agencies must be prepared to commit funds and personnel to solicit and coordinate additions to the list, to constantly maintain the list, and make it available to others.

Other complications with checklist inventories include the territory involved and changes in identifications, taxonomy, and nomenclature. These problems arose in the development of the checklists of the fishes of the Laurentian Great Lakes. Examples are given below.

Even when the word "basin" is not used in the title, the territory intended by the author often includes all tributary streams from the headwaters to the mouth at one of the lakes. The whole, or part, of the St. Lawrence River and its tributaries may also be included. Discussions either include lakes Nipigon and St. Clair separately because they contain species indigenous to the Great Lakes or are considered only as tributaries to lakes Superior and Erie, respectively. On the other hand, discussions may exclude Lake Nipigon and Lake St. Clair entirely .

Maintaining the most recent concept of nomenclature and taxonomy is a part of updating checklists. However, in attempting to do so, developing checklists can be extremely difficult. The cisco fauna of Lake Nipigon is a good example of this problem associated with checklists.

Lake Nipigon was once considered to contain an indigenous species of cisco, *Coregonus nipigon*. This was later thought to be synonymous with *C. artedi*. In 1980 it was suggested by Todd and Smith (1980) that *Coregonus nigripinnis* in Lake Nipigon were probably *C. artedi*. In 1992, in a table of the status of species of ciscoes in the Great Lakes (Todd and Smith 1992) *C. reighardi* was listed as extinct in lakes Ontario and Michigan, not present in lakes Erie and Superior, threatened in Lake Huron, and abundant in Lake Nipigon. Although this was a printer's error, readers of the paper were not aware of that problem. In the same publication, Fleisher (1992), possibly with a more limited concept of the Great Lakes, listed *C. reighardi* as extremely rare in the Laurentian Great Lakes, citing Todd and Smith (1992). In 1995, in a paper entitled, '*Coregonus reighardi* Koelz in the Laurentian Great Lakes', Webb and Todd (1995) suggested that "captures of only lone individuals in the last 16 years suggests the species may be extinct in all of the Laurentian system". The problem is that the Laurentian system in that paper did not include Lake Nipigon. As a result, the status at that time of that species in Lake Nipigon could have been misinterpreted by a hasty perusal of the abstract of that paper. When we were preparing these lists, we sought the advice of individuals involved with various species or working on specific lakes. We were advised at that time to include *C. reighardi* as globally extinct. By 1999, advice (Turgeon *et al.* 1999) was that C. *reighardi* had probably never occurred in Lake Nipigon, and that the populations referred to in the past were most likely *C. zenithicus*. Those authors recognized four *Coregonus* morphotypes (A,B,C,D) in Lake Nipigon that might be equated with previous descriptions of *C. artedi*, *C. zenithicus*, *C. nigripinnis* and *C. hoyi* respectively. They suggested that atypical individuals of B may represent specimens of *C. nipigon*. They warned, however, that "the poor genetic differentiation among these morphotypes does not support specific denominations" and continued to use the letter morphotypes. At present there is no agreement, and still confusion, over the status of forms to be recognized in Lake Nipigon.

The Great Lakes (Fig. 1), as we know them, appeared about 8,000 years ago after the retreat of the Wisconsinan Glacier. Fishes from several glacial refugia were the nucleus of the eventual assemblage of the Great Lakes fish communities (Underhill 1986). Each of the lakes has a different set of physical features (Table 1a), as do their connecting channels (Table 1b). Lake Nipigon is hydrologically the head of the Great Lakes system. The largest and the deepest of the Great Lakes is Lake Superior which discharges into lakes Huron and Michigan by way of

the St. Marys River, the longest of the connecting rivers. Lake Michigan is divided into two distinct basins: the southern basin with a gently sloping bottom which is shallower than the northern basin with its irregular bottom. Green Bay in northwestern Lake Michigan is generally more eutrophic and productive than the rest of the lake, yielding about half the total annual commercial fish catch for the lake. Lake Michigan is connected to Lake Huron by the Straits of Mackinac. Lake Huron is often divided into three sections for research and management: Lake Huron, North Channel and Georgian Bay, and drains through the St. Clair River into Lake St. Clair. Lake St. Clair drains through the Detroit River to Lake Erie. The southernmost lake within the Great Lakes system, Lake Erie, is the shallowest with an average depth of 19 metres. It is divided into three distinct basins: the eastern basin (the deepest), central basin, and western basin (the shallowest). Lake Erie flows into Lake Ontario via the Niagara River and a small amount of Lake Erie water also enters through the Welland Canal. Lake Ontario has one of the smallest surface areas of the Great Lakes although its volume of water is three and a half times that of Lake Erie.

The Great Lakes are an important ecological system, which contain nearly 20% of the earth's freshwater and support a diversity of microhabitats and life. The basin has played a major role in the history and development of both Canada and the United States, now supporting >10% of the US population and >25% of the Canadian population. The lakes also support the world's largest concentration of industries (The Nature Conservancy 1994). This pressure and high utilization in most of the lakes has contributed to some losses and declines in native species. Also, many introduced species have entered the lakes by various vectors such as authorized stocking programs, bait bucket release, and ballast water (Crossman and Cudmore 1998). Both losses and introductions have resulted in many changes in the diversity of the lakes over time. Catch statistics from commercial fisheries and scientific monitoring have made available a great quantity of documentation of changes in native and introduced species. There is a considerable amount of information available on introduced species (Emery 1985, Mills *et al.* 1993, Allan and Zarull 1995) and on changes in fish diversity over time (Smith 1968, Regier 1973, Christie 1974, Hartman 1988).

There have also been several lists developed detailing the composition of the fish fauna of the Great Lakes (Hubbs and Lagler 1947, Bailey and Smith 1981, Underhill 1986) These inventories, along with several other sources, were used in this update of the fish species

composition of the Great Lakes. This is a critical step towards conserving biodiversity (Wilson 1988) and can indicate later whether conservation methods and programs have been successful.

1.1 Great Lakes Fishery Commission Biodiversity Task

An increasing commitment to the ecosystem concept, and human concern for the changes in the biodiversity of the Great Lakes, led to the development in 1995 of the Biodiversity Task by the Board of Technical Experts (BOTE) of the Great Lakes Fishery Commission (GLFC). This three-year interdisciplinary task was given the title "The Role of Biodiversity in the Management of the Fishes of the Great Lakes". The task included three components: 1) the study of the changes in the food web and the ecological implications of these changes, 2) the relationship of changes in biodiversity to shifts in human values and conservation concepts, and 3) the component from which this paper was derived - the nature of, and causes of, changes in the biodiversity of the fishes of the Great Lakes (Crossman and Cudmore 1998).

The Biodiversity Task, as assigned by GLFC, limited consideration to the lakes alone as opposed to the basin. Although different from some previous considerations of the Laurentian Great Lakes, it was decided to include, and separate, lakes Nipigon and St. Clair for a total of seven Great Lakes. Another decision was to include the faunas of the interconnecting channels with that of a connected lake. As the fauna of the Nipigon River more closely resembles that of Lake Superior due to very early dam construction, the advice of biologists there suggested including the fauna in that of Lake Superior. Otherwise the faunas of outlet channels were included with that of the lake drained by the channel (e.g. Niagara River combined with Lake Erie). The fishes found in the large bays of the lakes were included with that lake (e.g. Georgian Bay included in Lake Huron). The St. Lawrence River was not to be included in the area covered, therefore Kingston, Ontario/Cape Vincent, New York was established as the downstream terminus.

The fishes included were to be those inhabiting the lakes plus only those stream species which could be considered to spend part of their life history in the lakes. We may have inadvertently used arbitrary decisions and possible incorrect records or decisions about some of the exceptions. Readers may disagree with the inclusion or absence of individual species in the various lists. All we can say in our defense is the list resulted from as exhaustive a literature search as possible (see App. B), and from the circulation of the list, at various stages in its development, to a number of field personnel familiar with the faunas of individual lakes (see

App. C). We received excellent responses from them. We added the species they added, and deleted any they suggested were in error. As a result the lists contain very recent information, up to August 2000. We do not intend to suggest we have made no errors. We suggest only that we felt it more appropriate to include possibly doubtful species than to ignore them. One of the functions of the lists is to establish as good as possible an approximation of the present biodiversity as a baseline against which to compare future information.

1.2 Terminology

Confusion can arise when developing or comparing inventories of species within a system. Differences in definitions and the development of new terminology can make decisions difficult for the inclusion or exclusion of species. For the purposes of this paper, we have used the following definitions:

biodiversity/diversity - the variety in the species composition of the fish community of the Great Lakes.

native - those species that were part of the Great Lakes fish community prior to the arrival of Europeans.

introduced species - those species that were not part of the Great Lakes fish community prior to the arrival of Europeans, and arrived through both natural and anthropogenic means.

established - reproducing in the Great Lakes or in the lowest reaches of the tributaries.

endemic - those species whose entire global range exists in the Great Lakes.

extirpated - those species no longer existing in part of their Great Lakes range but still found elsewhere in their global range

extinct - those species no longer existing in any part of their global range, including the Great Lakes.

forms - as a result of the presence of some hybrids, such as the splake and backcross, the term "forms" instead of "species" is often used when discussing the lists.

The following checklists are included in this paper – established forms present in each lake, introduced fishes occurring in each lake, and fishes extirpated from one or more of the Great Lakes.

2.0 METHODOLOGY

Common and scientific names follow Robins *et al.* (1991) and an unpublished update of

that list (Nelson *et al.* in press). In anticipation of this new edition of the American Fisheries Society List of Common and Scientific Names, we considered it useful that these lists for the Great Lakes not be in error as soon as published. Therefore, many of the decisions for the new names lists are included.

It was first important to update the available information on the changes in the biodiversity of the fishes of the Great Lakes. For the most part, information for this paper was derived from published and unpublished literature and databases from several different types of sources (App. A and B). This was done to develop draft checklists of the established fishes and of the introduced fishes of the Great Lakes. Established introduced species are found in both tables as different readers will be interested in one or the other of the subjects of the lists. The draft lists were sent to over 30 research and management agencies in the United States and Canada in order to get the most up-to-date information possible from people working closely with the fishes of the Great Lakes. Most of these agencies responded with input (App. C). To complete the documentation of historical changes in diversity, a third list provides details on species that have become extinct or extirpated from one or more of the Great Lakes. At the second and third of three workshops organized by the GLFC Biodiversity Task, the information in the lists was presented and relevant feedback from the workshops was incorporated in order to strengthen the accuracy of the checklists.

In order to develop an idea of potential future changes in diversity from introductions, a list was compiled of those species which may become introduced into the Great Lakes and Canadian waters of the lakes should global warming scenarios prove correct. This list was developed from lists by Mandrak (1989) and Mandrak and Crossman (1992).

3.0 RESULTS

There is a total of 142 established forms, both native and introduced, in the Great Lakes (Table 2), 55 introductions, reported and established (Table 3) and 26 species extirpated from one or more of the lakes (Table 4). The numbers of established forms in each of the lakes range from 116 to 40 forms (Table 5). Lake Michigan, at 116, has the highest number, Lake Huron the next highest, and lakes Superior and Nipigon the lowest (Table 5). Lake Ontario has three species listed as "possibly native", sea lamprey (*Petromyzon marinus*), alewife (*Alosa pseudoharengus*), and rainbow smelt (*Osmerus mordax*). Debate continues as to whether or not

these species are native to the lake. Overall, there have been 55 forms introduced into one or more of the Great Lakes, 25 of which are now established (Table 3). Lake Erie has the greatest number of introduced species, both reported and established, while lakes Nipigon and St. Clair have the lowest number. However, of the total number of established forms (both native and introduced), lakes Superior and Michigan have the highest percentage of established introduced forms at 17.4% and 17.2% respectively (Table 5).

Of the 26 forms lost from the lakes, 25 were native and include five of the six forms endemic to the Great Lakes. Of these 26 species extirpated, four are globally extinct, three of which were endemic to the lakes (Table 4). Lake Ontario has experienced the greatest loss (14 forms) followed by lakes Michigan (11), Erie (12), and Huron (9). Lakes St. Clair and Superior have each lost one form, although the species from Lake Superior, kokanee (*Oncorhynchus nerka*) was not native to the lake. Lake Nipigon has not lost any forms (Table 5).

Table 6 provides examples of some of the species which have, in the past, expanded their range northward into Canadian waters, along with their date of introduction. A list of those species which may extend their range northward in the future was also compiled (Table 7).

4.0 DISCUSSION

The many changes in the compositional diversity of the fishes of the Great Lakes has occurred through both losses and introductions of species. The diversity of the lakes is relatively low compared to that of other great lakes of the world. For example, Lake Malawi in Africa has as many as 1000 fish species with a degree of endemism of 95% (Lewis *et al.* 1986, McAllister *et al.* 1997). The degree of endemism for the Great Lakes is only 4%. Lake Michigan has many microhabitats which may be one of many reasons for the higher diversity of fishes found there (Wells and McLain 1973). Although Lake Superior has a relatively low number of established species compared to the rest of the lakes, the high percentage of introduced species is interesting (Table 5). This provides support to the idea that communities with lower biodiversity will have greater proportions of introduced species than those with higher diversity (Pimm 1991, Leach 1995). Leach (1995) also found Lake Superior had the greatest percentage of introduced species.

Comparing published lists of the composition of the fishes of the Great Lakes (such as: Hubbs and Lagler 1978, Bailey and Smith 1981, Emery 1985, Mills *et al.* 1993, 1994, Underhill 1986, and Coon 1999) is very difficult. The large discrepancy in species numbers between lists

is not the result of actual changes in numbers of species over time, but more the result of one or more of three factors. First, some of the lists use different boundaries to define the geographic area of study, for example lakes proper vs. basin. More specifically, the listing of species by Emery (1985) includes those species found in the entire Great Lakes basin, rarely differentiating between a tributary or lake record, while Bailey and Smith (1981) separated the species in the tributaries from those found in the the lakes proper. Second, definitions of native vs. introduced vary widely. For example, many lists consider *Petromyzon marinus* (sea lamprey) to be an introduced species to the upper lakes. However, Underhill's (1986) inventory list designated this species as native to all the upper lakes. Although some may view this as semantics, it underscores the need for clear definitions and the difficulty in comparing lists. Both of the above present real problems in attempts to inventory and monitor the fishes of the Great Lakes. Thirdly, records are much more accessible with the increase in the number and variety of databases now accessible through the internet. This problem with our ability to compare inventory lists serves to strengthen the argument that standardizing these lists is vitally important for effective monitoring of changes in diversity. Although losses and introductions are part of the natural dynamics of a community, the scale and rate has greatly increased due to human influences (Lodge 1993, Lovel 1997). There is a great need to conserve our resources and protect the biodiversity of the fishes of the Great Lakes. However, the ability to conserve and protect the resources diminishes if monitoring programs are based on inadequate knowledge of the fish composition of the lakes. There is also a need for more complete coordination of the methods used by the political entities responsible for managing those populations.

The loss of established species can lead to the loss of the role of that species within the community and the food webs. Lake Ontario has experienced the greatest loss of species compared to the rest of the lakes, perhaps as a result of the higher level and longer history of anthropogenic impacts experienced there (Sly 1991). The introduction of introduced species creates the potential for not only direct changes in community structure and function, but can also lead to further losses in native species (Crossman 1991, Lodge *et al.* 1998). These changes in biodiversity can have profound impacts on community structure, such as changes in the food web, and on function, such as productivity and nutrient cycling (Vitousek 1990). Another impact on the Great Lakes community may be a decrease in the ability to resist invasion by introduced species (Cudmore 1999). The potential for impacts of introduced species arises not only from

those species which become established, but also from those that are occasionally reported which have not yet become established. Those species have the potential to impact the fish fauna through competition for food, shelter and spawning habitat or by introducing diseases. It is important to track such species now so there is a baseline for comparisons in the future to determine what has become established and how long it took to do so. It is also important, for management purposed, to monitor these species and how they arrived here. Regulations may need to be developed if many species are being introduced via a specific vector.

The rate at which species, native and introduced, are expanding their distributional limits has also increased over the years. For the Great Lakes this expansion is usually north. In the 1950s species present to the south of the Great Lakes, or only in the southern tributaries of the lower lakes, appeared in Canadian waters at a rate no higher than one per decade (Table 6). Species new to Canadian waters of the lower lakes, or to the upper lakes, now arrive every two or three years. Not all of those that expand become established in the new area (e.g. of two populations of warmouth, *Chaenobryttus gulosus*, which became established on the north shore of Lake Erie, one has died out). Mandrak (1989) discussed this phenomenon listing 27 species as potential invaders northward. That list was expanded in 1992 (Mandrak and Crossman 1992) to a total of 40 species (Table 7).

Many losses and introductions have occurred in the fish fauna of the Laurentian Great Lakes with an increase in occurrence over the years. It is very likely that these biodiversity changes, especially from introductions (Ricciardi and Rasmussen 1998, Cudmore 1999), will continue into the future. To monitor these changes better and perhaps prevent or at least slow down unwanted changes, it is important that updates such as this one continue to be completed. Although inventory lists have inherent problems, they are vital tools used to monitor changing biodiversity and the results of conservation programs which are necessary in order to protect the integrity of the lakes and their fish resources.

Figure 1. The Laurentian Great Lakes.

Table 1a. Physical features of each Great Lake.

From: Fuller *et al.* (1995), except where noted below

Lake	Surface Area (km^2)	Maximum Depth (m)	Mean Depth (m)
Nipigon [a]	3 009	152	55
Superior	82 100	406	147
Michigan	57 800	282	85
Huron	95 600	229	59
St. Clair [b]	1 113	6	3
Erie	25 700	64	19
Ontario	18 960	244	86

[a] personal communication R. Salmon (Ontario Ministry of Natural Resources), maximum and mean depth are estimates only

[b] Herdendorf (1982)

Table 1b. Physical features of the connecting channels of the Great Lakes.

From: Edwards *et al.* (1989), except where noted below

Connecting Channel	River Length (km)	Annual Mean Discharge (m^3s^{-1})	Drop in Elevation (m)
Nipigon River[a]	48	365	76
St. Marys River	121	2100	6.7
St. Clair River	63	5097	1.5
Detroit River	41	5210	1.0
Niagara River	58	5692	99.3

[a] personal communication R. Salmon (Ontario Ministry of Natural Resources)

Table 2. Checklist of the established fishes of the Great Lakes.

It includes only those established fishes using the lakes for at least part of their life histories and those found in rivers considered for this purpose to be bodies of water connecting the lakes. Established is defined as reproducing in the lakes or lowest reaches of tributaries. In some cases fishes are included for which their fulfillment of the definition above is unclear [(?) = unsure if established and/or unsure if present for at least part of their life history in lake proper].

N = established, native; I = established, introduced; P = established, possibly native

Taxon	Nip	Sup	Mich	Hur	St. C	Erie	Ont
PETROMYZONTIDAE							
Ichthyomyzon castaneus (chestnut lamprey)			N				
Ichthyomyzon fossor (northern brook lamprey)		N	N	N		N	
Ichthyomyzon unicuspis (silver lamprey)		N	N	N	N	N	N
Lampetra appendix (American brook lamprey)		N	N	N			N
Petromyzon marinus (sea lamprey)		I	I	I	I	I	P
ACIPENSERIDAE							
Acipenser fulvescens (lake sturgeon)	N	N	N	N	N	N	N
LEPISOSTEIDAE							
Lepisosteus oculatus (spotted gar)			N		N	N	N
Lepisosteus osseus (longnose gar)		N	N	N	N	N	N
Lepisosteus platostomus (shortnose gar)			I				
AMIIDAE							
Amia calva (bowfin)			N	N	N	N	N
HIODONTIDAE							
Hiodon tergisus (mooneye)			N	N	N	N	N
ANGUILLIDAE							
Anguilla rostrata (American eel)							N

Table 2 continued

Taxon	Nip	Sup	Mich	Hur	St. C	Erie	Ont
CLUPEIDAE							
Alosa chrysochloris (skipjack herring)			I				
Alosa pseudoharengus (alewife)		I	I	I	I	I	P
Dorosoma cepedianum (gizzard shad)		I	I	I	I	I	I
CYPRINIDAE							
Campostoma anomalum (central stoneroller)			N	N	N	N	N
Carassius auratus (goldfish)			I	I	I	I	I
Couesius plumbeus (lake chub)	N	N	N	N	N		N
Cyprinella lutrensis (red shiner)			I				
Cyprinella spiloptera (spotfin shiner)			N	N	N	N	N
Cyprinus carpio (common carp)		I	I	I	I	I	I
Erimystax x-punctatus (gravel chub)					N		
Hybognathus hankinsoni (brassy minnow)		N	N	N		N	N
Luxilus chrysocephalus (striped shiner)			N	N	N	N	N
Luxilus cornutus (common shiner)		N	N	N	N	N	N
Lythrurus umbratilis (redfin shiner)			N	N	N	N	
Macrhybopsis storeriana (silver chub)					N	N	N
Margariscus margarita (pearl dace)	N	N	N	N		N	N
Nocomis biguttatus (hornyhead chub)		N	N	N	N	N	N
Nocomis micropogon (river chub)			N	N	N	N	N
Notemigonus crysoleucas (golden shiner)		N	N	N	N	N	N
Notropis anogenus (pugnose shiner)			N	N	N		N
Notropis atherinoides (emerald shiner)	N	N	N	N	N	N	N
Notropis bifrenatus (bridle shiner)							N
Notropis buccatus (silverjaw minnow)						N	
Notropis buchanani (ghost shiner)				I	I		
Notropis heterodon (blackchin shiner)		N	N	N	N		N
Notropis heterolepis (blacknose shiner)	N	N	N	N	N		N
Notropis hudsonius (spottail shiner)	N	N	N	N	N	N	N
Notropis ludibundus (sand shiner)		N	N	N	N	N	N
Notropis rubellus (rosyface shiner)			N	N	N	N	N
Notropis volucellus (mimic shiner)	N	N	N	N	N	N	N
Opsopoeodus emiliae (pugnose minnow)			N		N		

Table 2 continued

Taxon	Nip	Sup	Mich	Hur	St. C	Erie	Ont
Phoxinus eos (northern redbelly dace)	N	N	N	N		N	N
Phoxinus neogaeus (finescale dace)	N	N	N	N			N
Pimephales notatus (bluntnose minnow)		N	N	N	N	N	N
Pimephales promelas (fathead minnow)	N	N	N	N	N	N	N
Rhinichthys atratulus (blacknose dace)		N	N	N	N	N	N
Rhinichthys cataractae (longnose dace)	N	N	N	N		N	N
Scardinius erythrophthalmus (rudd)			I			I	I
Semotilus atromaculatus (creek chub)		N	N	N	N	N	N
Semotilus corporalis (fallfish)							N
CATOSTOMIDAE							
Carpiodes cyprinus (quillback)			N	N	N	N	N
Catostomus catostomus (longnose sucker)	N	N	N	N	N	N	N
Catostomus commersonii (white sucker)	N	N	N	N	N	N	N
Erimyzon oblongus (creek chubsucker)			N			N	N
Erimyzon sucetta (lake chubsucker)			N	N	N	N	N
Hypentelium nigricans (northern hog sucker)			N	N	N	N	N
Ictiobus cyprinellus (bigmouth buffalo)			I		I	I	
Minytrema melanops (spotted sucker)			N	N	N	N	
Moxostoma anisurum (silver redhorse)	N	N	N	N	N	N	N
Moxostoma duquesneii (black redhorse)				N		N	
Moxostoma erythrurum (golden redhorse)			N	N	N	N	N
Moxostoma macrolepidotum (shorthead redhorse)	N	N	N	N	N	N	N
Moxostoma valenciennesi (greater redhorse)		N	N	N	N	N	N
COBITIDAE							
Misgurnus anguillicaudatus (oriental weatherfish)			I	I			
ICTALURIDAE							
Ameiurus melas (black bullhead)	N	N	N	N	N	N	
Ameiurus natalis (yellow bullhead)		N	N	N	N	N	N
Ameiurus nebulosus (brown bullhead)		N	N	N	N	N	N
Ictalurus punctatus (channel catfish)		N	N	N	N	N	N
Noturus flavus (stonecat)		N	N	N	N	N	N

Table 2 continued

Taxon	Nip	Sup	Mich	Hur	St. C	Erie	Ont
Noturus gyrinus (tadpole madtom)		N	N	N	N	N	N
Noturus miurus (brindled madtom)					N	N	
Noturus stigmosus (northern madtom)				N	N	N	
Pylodictis olivaris (flathead catfish)			N?			N?	
ESOCIDAE							
Esox americanus vermiculatus (grass pickerel)			N	N	N	N	N
Esox lucius (northern pike)	N	N	N	N	N	N	N
Esox masquinongy (muskellunge)		N	N	N	N	N	N
Esox niger (chain pickerel)							I
UMBRIDAE							
Umbra limi (central mudminnow)		N	N	N	N	N	N
OSMERIDAE							
Osmerus mordax (rainbow smelt)	I	I	I	I	I	I	P
SALMONIDAE							
Coregonus artedi (lake herring)	N	N	N	N		N	N
Coregonus clupeaformis (lake whitefish)	N	N	N	N	N	N	N
Coregonus hoyi (bloater)	N	N	N	N			
Coregonus kiyi (kiyi)		N					
Coregonus zenithicus (shortjaw cisco)	N	N					
Oncorhynchus gorbuscha (pink salmon)		I	I	I		I	I
Oncorhynchus kisutch (coho salmon)		I	I	I	I	I	I
Oncorhynchus mykiss (rainbow trout)		I	I	I	I	I	I
Oncorhynchus tshawytscha (chinook salmon)		I	I	I	I	I	I
Prosopium coulterii (pygmy whitefish)		N					
Prosopium cylindraceum (round whitefish)	N	N	N	N			N
Salmo trutta (brown trout)	I	I	I	I	I	I	I
Salvelinus fontinalis (brook trout)	N	N	N	N	N?		
Salvelinus namaycush (lake trout)	N	N	N	N	N		N
Salvelinus namaycush siscowet		N					

Table 2 continued

Taxon	Nip	Sup	Mich	Hur	St. C	Erie	Ont
PERCOPSIDAE							
Percopsis omiscomaycus (trout-perch)	N	N	N	N	N	N	N
APHREDODERIDAE							
Aphredoderus sayanus (pirate perch)			N?	N?		N	N
GADIDAE							
Lota lota (burbot)	N	N	N	N	N	N	N
ATHERINIDAE							
Labidesthes sicculus (brook silverside)			N	N	N	N	N
FUNDULIDAE							
Fundulus diaphanus (banded killifish)			N	N	N	N	N
Fundulus notatus (blackstripe topminnow)			N?				
GASTEROSTEIDAE							
Apeltes quadracus (fourspine stickleback)		I					
Culaea inconstans (brook stickleback)	N	N	N	N	N	N	N
Gasterosteus aculeatus (threespine stickleback)		I	I	I	I	I	N
Pungitius pungitius (ninespine stickleback)	N	N	N	N	N		N
COTTIDAE							
Cottus bairdii (mottled sculpin)	N	N	N	N		N	N
Cottus cognatus (slimy sculpin)	N	N	N	N	N		N
Cottus ricei (spoonhead sculpin)	N	N		N			
Myoxocephalus thompsonii (deepwater sculpin)	N	N	N	N		N	N
MORONIDAE							
Morone americana (white perch)		I	I	I	I	I	I
Morone chrysops (white bass)		N	N	N	N	N	N

Table 2 continued

Taxon	Nip	Sup	Mich	Hur	St. C	Erie	Ont
CENTRARCHIDAE							
Ambloplites rupestris (rock bass)		N	N	N	N	N	N
Chaenobryttus gulosus (warmouth)						N	
Lepomis cyanellus (green sunfish)				N	N	N	N
Lepomis gibbosus (pumpkinseed)		N	N	N	N	N	N
Lepomis humilis (orangespotted sunfish)					N	N	
Lepomis macrochirus (bluegill)		N	N	N	N	N	N
Lepomis megalotis (longear sunfish)			N	N		N	N
Micropterus dolomieu (smallmouth bass)		N	N	N	N	N	N
Micropterus salmoides (largemouth bass)		N	N	N	N	N	N
Pomoxis annularis (white crappie)			N	N	N	N	N
Pomoxis nigromaculatus (black crappie)		N	N	N	N	N	N
PERCIDAE							
Ammocrypta pellucida (eastern sand darter)				N	N	N	
Etheostoma blennioides (greenside darter)				N	N	N	
Etheostoma caeruleum (rainbow darter)			N	N		N	N
Etheostoma exile (Iowa darter)	N	N	N	N	N	N	N
Etheostoma flabellare (fantail darter)		N	N	N	N	N	N
Etheostoma microperca (least darter)		N	N	N	N		N
Etheostoma nigrum (johnny darter)	N	N	N	N	N	N	N
Etheostoma olmstedi (tessellated darter)							N
Gymnocephalus cernuus (ruffe)		I		I			
Perca flavescens (yellow perch)	N	N	N	N	N	N	N
Percina caprodes (logperch)	N	N	N	N	N	N	N
Percina copelandi (channel darter)				N	N	N	N
Percina maculata (blackside darter)			N	N	N	N	N
Percina shumardi (river darter)			N?	N?	N?	N?	
Stizostedion canadense (sauger)	N	N	N	N	N		
Stizostedion vitreum (walleye)	N	N	N	N	N	N	N
SCIAENIDAE							
Aplodinotus grunniens (freshwater drum)		I	N	N	N	N	N

Table 2 continued

Taxon	Nip	Sup	Mich	Hur	St. C	Erie	Ont
GOBIIDAE							
Neogobius melanostomus (round goby)			I	I	I	I	
Proterorhinus marmoratus (tubenose goby)				I	I	I	

Table 3. Introduced fishes occurring in each Great Lake.

I = established, introduced; R= reported, introduced, not likely established (unsuccessful);

P= possibly native; ?= uncertain if introduced

Taxon	Nip	Sup	Mich	Hur	St.C	Erie	Ont
PETROMYZONTIDAE							
Petromyzon marinus (sea lamprey)		I	I	I	I	I	P
LEPISOSTEIDAE							
Lepisosteus oculatus (spotted gar)							R
Lepisosteus platostomus (shortnose gar)			I				
ANGUILLIDAE							
Anguilla rostrata (American eel)		R	R	R		R	
CLUPEIDAE							
Alosa aestivalis (blueback herring)							R
Alosa chrysochloris (skipjack herring)			I			R	
Alosa pseudoharengus (alewife)		I	I	I	I	I	P
Alosa sapidissima (American shad)			R	R		R	R
Dorosoma cepedianum (gizzard shad)		I	I	I	I	I	I
CYPRINIDAE							
Carassius auratus (goldfish)			I	I	I	I	I
Ctenopharyngodon idella (grass carp)			R	R	R	R	R
Cyprinella lutrensis (red shiner)			I				
Cyprinus carpio (common carp)		I	I	I	I	I	I
Hypophthalmichthys nobilis (bighead carp)						R	
Notropis buchanani (ghost shiner)				I	I		
Phenacobius mirabilis (suckermouth minnow)						R	
Scardinius erythrophthalmus (rudd)			I			I	I
COBITIDAE							
Misgurnus anguillicaudatus (Oriental weatherfish)			I	I			
CATOSTOMIDAE							
Ictiobus cyprinellus (bigmouth buffalo)			I		I	I	R
Ictiobus niger (black buffalo)			R	R		R	
CHARACIDAE							
Piaractus brachypomus (pirapatinga)				R		R	R
Myleus pacu (pacu)				R	R	R	
Pygocentrus nattereri (red pirahna)				R	R	R	

Table 3 continued

Taxon	Nip	Sup	Mich	Hur	St.C	Erie	Ont
ICTALURIDAE							
Ameiurus catus (white catfish)						R	
LORICARIIDAE							
Lyposarcus pardalis (suckermouth catfish)						R	
ESOCIDAE							
Esox niger (chain pickerel)							I
OSMERIDAE							
Osmerus mordax (rainbow smelt)	I	I	I	I	I	I	P
SALMONIDAE							
Coregonus moraena (German whitefish)			R	R?			
Oncorhynchus gorbuscha (pink salmon)		I	I	I		I	I
Oncorhynchus kisutch (coho salmon)		I	I	I	I	I	I
Oncorhynchus mykiss (rainbow trout)		I	I	I	I	I	I
Oncorhynchus nerka (kokanee)		R	R	R			R
Oncorhynchus tshawytscha (chinook salmon)		I	I	I	I	I	I
Prosopium cylindraceum (round whitefish)						R	
Salmo clarkii (cutthroat trout)				R			
Salmo salar (Atlantic salmon) landlocked & anadromous		R	R	R	R	R	R
Salmo trutta (brown trout)	I	I	I	I	I	I	I
Salvelinus alpinus (Arctic char)							R
S. fontinalis X *S. namaycush* (splake)		R		R			R
(*S. fontinalis* X *S. namaycush*)X *S. namaycush* (backcross)				R			
Thymallus arcticus (Arctic grayling)		R					
POECILIIDAE							
Gambusia affinis (western mosquitofish)			R			R	
GASTEROSTEIDAE							
Apeltes quadracus (fourspine stickleback)		I					
Gasterosteus aculeatus (threespine stickleback)		I	I	I	I	I	
MORONIDAE							
Morone americana (white perch)		I	I	I	I	I	I
Morone mississippiensis (yellow bass)			R	R			
Morone saxatilis (striped bass)			R	R		R	R
Morone hybrid			R			R	R
CENTRARCHIDAE							
Micropterus dolomieu (smallmouth bass)	R						

Table 3 continued

Taxon	Nip	Sup	Mich	Hur	St.C	Erie	Ont
PERCIDAE							
Gymnocephalus cernuus (ruffe)		I		I			
SCIAENIDAE							
Aplodinotus grunniens (freshwater drum)		I					
CICHLIDAE							
Astronotus ocellatus (oscar)						R	
GOBIIDAE							
Neogobius melanostomus (round goby)		R	I	I	I	I	R
Proterorhinus marmoratus (tubenose goby)				I	I	I	
PLEURONECTIDAE							
Platichthys flesus (European flounder)		R	R	R	R	R	

Table 4. Fishes extirpated from one or more of the Great Lakes.

* = globally extinct

Taxon	Nip	Sup	Mich	Hur	St.C	Erie	Ont
POLYODONTIDAE							
Polyodon spathula (paddlefish)			x	x		x	
CLUPEIDAE							
Alosa sapidissima (American shad)							x
CYPRINIDAE							
Macrhybopsis storeriana (silver chub)			x				
Notropis amblops (bigeye chub)							x
Notropis anogenus (pugnose shiner)						x	
Notropis heterodon (blackchin shiner)						x	
Notropis heterolepis (blacknose shiner)						x	
Phoxinus neogaeus (finescale dace)					x		
SALMONIDAE							
Coregonus hoyi (bloater)							x
**Coregonus johannae* (deepwater cisco)			x	x			
Coregonus kiyi (kiyi)			x	x			x
**Coregonus nigripinnis* (blackfin cisco)			x	x			
**Coregonus reighardi* (shortnose cisco)			x	x			x
Coregonus zenithicus (shortjaw cisco)			x	x		x	x
Salmo salar (Atlantic salmon) original genetic stock							x
Salvelinus namaycush (lake trout) original genetic stocks			x	x		x	x
Oncorhynchus nerka (sockeye)		x	x	x			x
COTTIDAE							
Cottus cognatus (slimy sculpin)						x	
Cottus ricei (spoonhead sculpin)			x			x	x
Myoxocephalus thompsoni (deepwater sculpin)						x	
CENTRARCHIDAE							
Enneacanthus gloriosus (bluespotted sunfish)							x
Lepomis megalotis peltastes (longear sunfish)						x	
PERCIDAE							
Etheostoma chlorosoma (bluntnosed darter)			x				
Etheostoma microperca (least darter)							x
Stizostedion canadense (sauger)						x	x
**Stizostedion vitreum glaucum* (blue pike)				x		x	x

Table 5. Summary table of number of fishes occurring in each Great Lake.

N = established, native

I = established, introduced

P = established, possibly native

R= reported, introduced not likely established

	Nip	Sup	Mich	Hur	St.C	Erie	Ont
Established native (N)	38	71	96	97	86	90	92
Established introduced (I)	2	15	20	18	16	17	11
Possibly native (P)	0	0	0	0	0	0	3
TOTAL ESTABLISHED (N+I+P)	**40**	**86**	**116**	**115**	**102**	**107**	**106**
% OF TOTAL ESTABLISHED WHICH ARE ESTABLISHED INTRODUCTIONS	**5.0**	**17.4**	**17.2**	**15.7**	**15.7**	**15.9**	**10.3 (or +3P= 13.2)**
Reported introduced (R)	1	7	12	16	5	19	13 (+3P)
TOTAL INTRODUCED (I + R)	**3**	**22**	**32**	**34**	**21**	**36**	**24 (+ 3P)**
TOTAL EXTIRPATED/EXTINCT	**0**	**1**	**11**	**9**	**1**	**12**	**14**

Table 6. Species originally native to, or occurring in, only the US waters of the Great Lakes basin which have invaded northward into Canadian waters, where they are considered introduced.

Taxon	Lake Arrived	Date First Recorded in Canadian Waters
Erimyzon sucetta (lake chubsucker)	Erie	1949
Ictiobus cyprinellus (bigmouth buffalo)	Erie	1957
Ictiobus niger (black buffalo)	Erie	1978
Minytrema melanops (spotted sucker)	Erie	1962
Noturus stigmosus (northern madtom)	St. Clair	1963
Pylodictis olivaris (flathead catfish)	Erie	1978
Chaenobryttus gulosus (warmouth)	Erie	1966
Lepomis humilis (orangespotted sunfish)	tributaries to Erie	1980

Table 7. List of potential invaders into the Great Lakes or into the northern portions of the lakes should global warming continue.

Species with * are based on proximity alone, the others on proximity plus ecological requirements. From: Mandrak (1989) and Mandrak and Crossman (1992).

ACIPENSERIDAE
Scaphirhynchus platorynchus (shovelnose sturgeon)

LEPISOSTEIDAE
Lepisosteus oculatus (spotted gar)
Lepisosteus platostomus (shortnose gar)

HIODONTIDAE
Hiodon alosoides (goldeye)

CYPRINIDAE
Cyprinella venusta (blacktail shiner)
Cyprinella whippleii (steelcolor shiner)
**Exoglossum laurae* (tonguetied minnow)
Hybognathus placitus (plains minnow)
**Notropis amblops* (bigeye chub)
Notropis blennius (river shiner)
**Notropis buccatus* (silverjaw minnow)
Notropis chalybaeus (ironcolor shiner)
Notropis dorsalis (bigmouth shiner)
Notropis nubilus (Ozark minnow)
**Notropis texanus* (weed shiner)
**Phenacobius mirabilis* (suckermouth minnow)
**Phoxinus erythrogaster* (southern redbelly dace)
**Semotilus corporalis* (fallfish)

CATOSTOMIDAE
Carpiodes carpio (river carpsucker)
Cycleptus elongatus (blue sucker)
Moxostoma carinatum (river redhorse)

ESOCIDAE
**Esox americanus americanus* (redfin pickerel)
Esox americanus vermiculatus (grass pickerel)
Esox niger (chain pickerel)

FUNDULIDAE
Fundulus chrysotus (golden topminnow)

Table 7 continued

Fundulus olivaceus (blackspotted topminnow)
Fundulus sciadicus (plains topminnow)

CENTRARCHIDAE
Acantharchus pomotis (mud sunfish)
Centrarchus macropterus (flier)
Enneacanthus chaetodon (blackbanded sunfish)
**Enneacanthus gloriosus* (bluespotted sunfish)
Enneacanthus obesus (banded sunfish)
**Lepomis megalotis* (longear sunfish)
**Lepomis microlophus* (redear sunfish)
Lepomis symmetricus (bantam sunfish)

PERCIDAE
**Etheostoma spectabile* (orangethroat darter)
**Etheostoma variatum* (variegate darter)
**Etheostoma zonale* (banded darter)

ELASSOMATIDAE
Elassoma zonatum (banded pygmy sunfish)

GOBIIDAE
**Proterorhinus marmoratus* (tubenose goby)

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Appendix A. List of agencies, organizations, and databases which were sources of information.

A. Government Agencies

1. Ontario Ministry of Natural Resources
2. Environment Canada
3. Department of Fisheries and Oceans
4. United States Fish and Wildlife Service (USFWS)
5. United States Geological Survey
6. The state natural resource management agencies of the eight American states bordering the Great Lakes
7. Great Lakes Fishery Commission
8. Ontario Hydro
9. International Joint Commission

B. Academic Organizations

1. University of Toronto
2. University of Minnesota
3. Duke University Marine Lab
4. University of Guelph
5. Cornell University
6. Lakehead University
7. United States' National Sea Grant Programs

C. Non-Governmental Organizations

1. Federation of Ontario Naturalists
2. Great Lakes United
3. Ontario Commercial Fisheries' Association
4. Great Lakes Sport Fishing Council
5. North American Native Fishes Aquarium Association
6. Ontario Aquaculture Association
7. Lake Huron Fishing Club
8. Great Lakes Commission
9. National Wildlife Federation
10. Ontario Federation of Anglers' & Hunters'

D. Museums

1. Royal Ontario Museum
2. Canadian Museum of Nature
3. The University of Michigan, Museum of Zoology
4. University of Minnesota, James Ford Bell Museum of Natural History

E. Libraries

1. Ontario Ministry of Natural Resources
2. Royal Ontario Museum
3. University of Toronto
4. Metro Toronto Reference Library
5. Ontario Hydro

F. Databases

1. Canadian Heritage Information Network
2. Royal Ontario Museum, Ichthyology and Herpetology Section
3. University of Michigan, Museum of Zoology, Fish Section
4. United States Geological Survey, Department of the Interior, Non-Indigenous Aquatic Species
5. OMNR, Lake St. Clair Young-of-the-Year database
6. FishBase

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Tom Todd, Great Lakes Science Center
James Underhill, University of Minnesota

Appendix C. Agencies who responded with input to the checklists.

Canada

Ontario Ministry of Natural Resources (OMNR), Lake Ontario Management Unit
OMNR, Lake Erie Management Unit
OMNR, Lake Erie Fisheries Station
OMNR, Lake St. Clair Fisheries Station
OMNR, Lake Huron Management Unit
OMNR, Lake Superior Management Unit
OMNR, Lake Nipigon Fisheries Assessment Unit
Department of Fisheries and Oceans (DFO), Sea Lamprey Control Program

United States

United States Fish and Wildlife Service (USFWS), Lower Great Lakes Fishery Resource Center
USFWS, Sea Lamprey Control Program, Marquette, MI
New York Department of Environmental Conservation
New York Sea Grant Program
Pennsylvania Fish and Boat Commission
Michigan Department of Natural Resources (MIDNR), Office of the Great Lakes
MIDNR, Mt. Clemens Fisheries Station
MIDNR, Marquette Fisheries Station
Indiana Department of Natural Resources
Illinois Department of Natural Resources
Wisconsin Department of Natural Resources
Wisconsin Sea Grant Program
Minnesota Department of Natural Resources
National Biological Service (NBS), Lake Ontario Biological Station
NBS, Lake Huron Biological Station
NBS, Lake Erie Biological Station
University of Minnesota, James Ford Bell Museum of Natural History

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